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A SINGLE-PHASE TRANSFORMERLESS INVERTER WITH A CHARGE PUMP CIRCUIT CONCEPT FOR GRID-TIED PV APPLICATIONS

Miss MADASU LAYA[1], MRS. A.ANURADHA[2]

[1]PG scholar in the Dept. of Electrical & Electronics Engineering, in Holy Mary Institute of Technology & Science, Bogaram (V), Medchal District, Hyderabad, India.

[2]Assistant Professor in the Dept. of Electrical & Electronics Engineering, in Holy Mary Institute of Technology & Science, Bogaram (V), Medchal District, Hyderabad, India.

Abstract : This paper proposes a new single-phase transformer-less photovoltaic (PV) inverter for grid-tied PV systems. The topology is derived from the concept of a charge pump circuit in order to eliminate the leakage current. It is composed of four power switches, two diodes, two capacitors, and an LCL output filter. The neutral of the grid is directly connected to the negative polarity of the PV panel which creates a constant common mode voltage and zero leakage current. The charge pump circuit generates the negative output voltage of the proposed inverter during the negative cycle. A proportional resonant control strategy is used to control the injected current. The main benefits of the proposed inverter are: 1) the neutral of the grid is directly connected to the negative terminal of the PV panel, so the leakage current is eliminated; 2) its compact size; 3) low cost; 4) the used DC voltage of the proposed inverter is the same as the full-bridge inverter (unlike neutral point clamped (NPC), active NPC, and half-bridge inverters); 5) flexible grounding configuration; 6) capability of reactive power flow; and 7) high efficiency. A complete description of the operating principle and analysis of the proposed inverter are presented. Experimental results are presented to confirm both the theoretical analysis and the concept of the proposed inverter. The obtained results clearly validate the performance of the proposed inverter and its practical application in grid-tied PV systems.

***IndexTerms* -** Photovoltaic, transformer-less, power switches, resonant control strategy, reactive power, neutral point clamped (NPC).

I. INTRODUCTION

In the last two decades, the Photovoltaic (PV) power systems have become very popular among the renewable energy sources, because they generate electricity with no moving parts, operate quietly with no emissions, and require little maintenance [1], [2]. Distributed grid connected PVs are playing an increasingly role as an integral part of the electrical grid. However, due to the large stray capacitors between the PV panels and the ground, PV systems suffer from a high common mode current, which reduces the system efficiency and may cause safety issues like electric shock. In order to eliminate the leakage currents, transformers are commonly used in the PV system to provide galvanic isolation. However, it possesses undesirable properties including large size, high cost and weight with additional losses [3]. Thus, eliminating the transformer is a great benefit to further improve the overall system efficiency, reduce the size, and weight [4]. One of the important issues in the transformerless grid connected PV applications is the galvanic connection of the grid and PV system, which leads to leakage current problems. For transformerless grid connected inverters, Full Bridge (FB) inverter, Neutral Point Clamped (NPC), Active NPC (ANPC) inverter [5] and many other topologies such as H5, H6 and HERIC were proposed to reduce the leakage current with disconnecting of the grid from the PV during the freewheeling modes [6]. However, these topologies are not totally free from Common Mode (CM) current or leakage current. The leakage current still exists due to the parasitic capacitor of the switch and stray capacitance between the PV panel and ground. So, some of these topologies require two or more filter inductors to reduce the leakage current, which leads to a rise in the volume and cost of the system [7]. Fig. 1 illustrates a single-phase grid tied transformerless inverter with CM current path, where P and N are the positive and negative terminals of the PV, respectively.

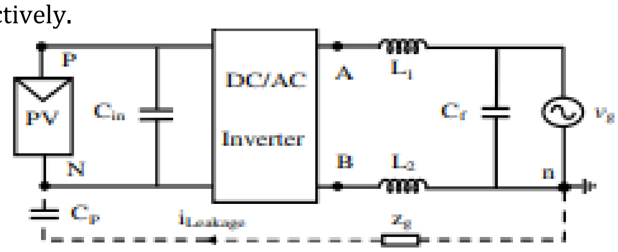

Fig. 1. Block diagram of single-phase grid connected transformerless inverter with a leakage current path.

The leakage current (iLeakage) flows through parasitic capacitor (CP) between the filters (L1 and L2), the inverter, grid and ground impedance (zg). This leakage current may cause safety problems, reduce the quality of injection current to the grid, as well as decrease the system efficiency [8]. In order to eliminate the leakage current, the Common Mode Voltage (CMV) (vcm) must be kept constant during all operation modes according to [9]. The vcm with two filter inductors (L1, L2) is calculated as:

$$v_{\mathrm{cm}} = \frac{v_{\mathrm{An}} + v_{\mathrm{Bn}}}{2} + \frac{(v_{\mathrm{An}} - v_{\mathrm{Bn}})(L_2 - L_1)}{2(L_1 + L_2)} \quad \text{……………1.1}$$

where, vAn and vBn are the voltage differences between the midpoints A and B of the inverter to the dc bus minus terminal N, respectively. If L1 ≠ L2 (asymmetrical inductor), vcm is calculated according to (1) and the leakage current appears due to a varying CMV. If L1 = L2 (symmetrical inductor), vcm is simplified to:

$$v_{\mathrm{cm}} = \frac{v_{\mathrm{An}} + v_{\mathrm{Bn}}}{2} = \mathrm{Const.} \quad \text{……………………1.2}$$

in this state, the common mode voltage is constant and the leakage current is eliminated. In some structures such as the virtual dc bus inverter [10] and NPC inverter, one of the filter inductors is zero and only one filter inductor is used. In this state, after simplification of vcm, it will have a constant value according to (3) and the leakage current will be eliminated. As shown in Fig. 1.2, there are various transformerless grid connected inverters based on the FB inverter in the literature to overcome these problems.

$$v_{\mathrm{cm}} = \frac{v_{\mathrm{An}} + v_{\mathrm{Bn}}}{2} + \frac{v_{\mathrm{An}} - v_{\mathrm{Bn}}}{2} = \mathrm{Const.} \quad (L_1 = 0)$$

$$v_{\mathrm{cm}} = \frac{v_{\mathrm{An}} + v_{\mathrm{Bn}}}{2} - \frac{v_{\mathrm{An}} - v_{\mathrm{Bn}}}{2} = \mathrm{Const.} \quad (L_2 = 0). \quad \text{…………1.3}$$

The H5 inverter that is a FB based inverter topology, compared to the conventional FB inverter, needs one additional switch (S5) on the dc side to decouple the dc side from the grid as shown in Fig. 2(a). This inverter has a variable CM voltage with a small leakage current and it suffers from low efficiency due to three switches operating at the same time [11]. As shown in Fig. 2(b), the Highly Efficient and Reliable Inverter Concept (HERIC) topology needs two extra switches on the ac side to decouple the ac side from the PV module in the zero stage. HERIC combines the merits of unipolar and bipolar modulation. The main advantage of the HERIC inverter is its high efficiency due to only two switches operates at the same time in all operation modes. The main drawbacks of the HERIC topology are its the low frequency harmonics and reactive power flow is not allowed [12]. Topologies based on H6 are also proposed in [13], [14] to eliminate the leakage current of the grid tied PV application. These inverters consist of six power switches and some diodes for disconnecting the dc side from the grid.
These topologies are more costly than the FB inverter, because they use extra switches and diodes. Another disadvantage of these topologies is lower efficiency due to the current that circulates through three power switches at the same time [15]. Several high efficient new H6 transformerless inverters are proposed in [16], [17] to achieve light weight and also lower cost. They have the capability of reactive power injection to the grid. The leakage current is not totally eliminated in these topologies, which is the main disadvantage of them. Another solution to eliminate the leakage current is the direct connection of the negative PV terminal to the neutral point of the grid, such as the virtual dc bus inverter in [10] and the unusual topology in [18]. In these topologies, the leakage current is completely eliminated by the topology structure. As shown in Fig. 2(c), the virtual dc bus inverter is composed of five IGBTs, two capacitors and one filter inductor Lf . Only one filter inductor is used in this topology to eliminate the leakage current, but it is very large. The virtual dc bus generates the negative output voltage. The main drawback of this topology is that there is no path to charge the capacitor C2 during the negative cycle and this will cause a high output THD. The topology presented in [18], which is shown in Fig. 1.2(d) has a common ground with the grid. The number of semiconductors used in this topology is low. However, the output voltage of this inverter is only two levels including positive and negative voltage without creating the zero voltage, which requires a large output inductor L2 and a filter. The inductor medium-type inverter [19] also called "Karschny" is another topology that is derived from the buck-boost topology. This inverter has a high reliability without capability of giving the reactive power to the grid and has four power switches in the current path at the same time, which will reduce the efficiency.

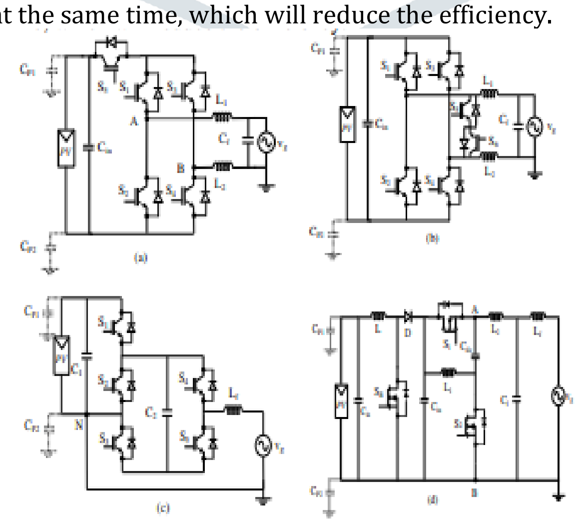

Fig. 2. Single phase grid tied transformerless PV inverter topologies: (a) H5 inverter (b) HERIC inverter (c) virtual dc bus inverter [10] (d) common mode inverter proposed in [18].

This paper introduces a new transformerless inverter based on charge pump circuit concept, which eliminates the leakage current of the grid-connected PV systems using a unipolar sinusoidal pulse width modulation (SPWM) technique. In this solution, the neutral of the grid is directly connected to the negative terminal of the charge pump circuit, so the voltage across the parasitic capacitor is connected to zero and the leakage current is eliminated. The charge pump circuit is implemented to generate negative output voltage. There is not any limitation on the modulation strategy of the proposed inverter because the leakage current is eliminated by the circuit topology. The proposed topology consists of only four power switches, so the cost of the semiconductors is reduced and the power quality is improved by three-level output voltage in order to reduce the output current ripple. During operation of the proposed inverter, the current flows through two switches; thus, the conduction loss is also lower. The used dc voltage of the proposed inverter is the same as the FB inverter (unlike NPC, ANPC, and half-bridge (HB) inverters). The proposed inverter is capable of delivering reactive power into grid too.

II. OPERATING PRINCIPLE OF BIDIRECTIONAL AC – DCCONVERTER

Fig. 6.1 shows the four sub operational modes as rectifier and electrical converter severally. The four sub operational modes rely upon the physical phenomenon standing of switches A1, A2, D1 and D2.

A. Rectifier Mode

Within the positive 0.5 cycle of grid current as shown in Fig. 6.1 (a), leg A1 and D1 operates. Once A1 is ON, current iac will increase as a result of the voltage across inductance L1 is positive as shown in Fig. 3 (b). Electrical condenser C1 is discharged, and therefore the energy of each C1 and C2 is transferred to the DC aspect. Once A1 is OFF and D1 is ON, current iac decreases as a result of the voltage across inductance L1 is negative as shown in Fig 3 (c). Electrical condenser C2 is charged, and therefore the energy of each C1 and C2 is transferred to the DC supply. Within the negative 0.5 cycle, legs A2 and D2 operate. Once A2 is ON, current iac will increase as a result of the voltage across inductance L2 is positive as shown in Fig. 3 (d). Electrical condenser C2 is discharged, and therefore the energy of each C1 and C2 is transferred to the DC supply. Once A2 is OFF and D2 is ON, current iac decreases as a result of the voltage across the inductance L2 is negative as shown in Fig. 3 (e). Electrical condenser C1 is charged, and therefore the energy of each C1 and C2 is transferred to the DC sources. Overall, within the positive 0.5 cycle, C1 is often discharged, however C2 is often charged. However, within the negative 0.5 cycle, C1 is often charged, however C2 is often discharged. The charge balance is maintained through the complete line cycle.

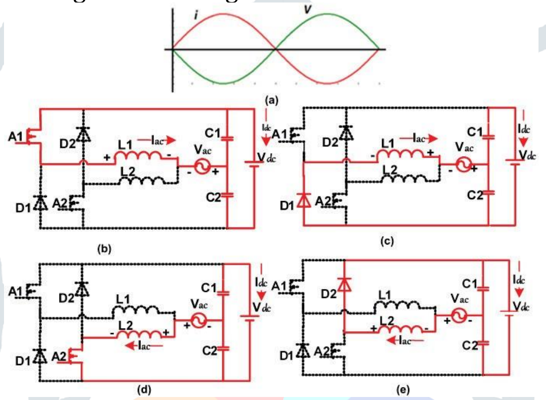

Fig. 3 Operating under rectifier mode with pure active power transferring. (a) Conceptual Voltage and Current waveforms. (b) A1 is ON.(c)D1isON.(d)A2isON.(e)D2isON.

B. Inverter mode: The inverter-modes with pure active power transfer unit shown in Figs 4 (b), 4 (c),4 (d) and 4 (e). All the analysis is similar to it of rectifier mode, except that the current and voltage unit in section as shown in Fig 6.2 (a). The energy is transferred from DC sources to AC grid. supported a similar analysis, it square measure typically terminated that C2 is commonly charged at intervals the positive zero.5 cycle and C1 is commonly charged at intervals the negative zero.5 cycle, and thus the charge balance maintains through the full line cycle

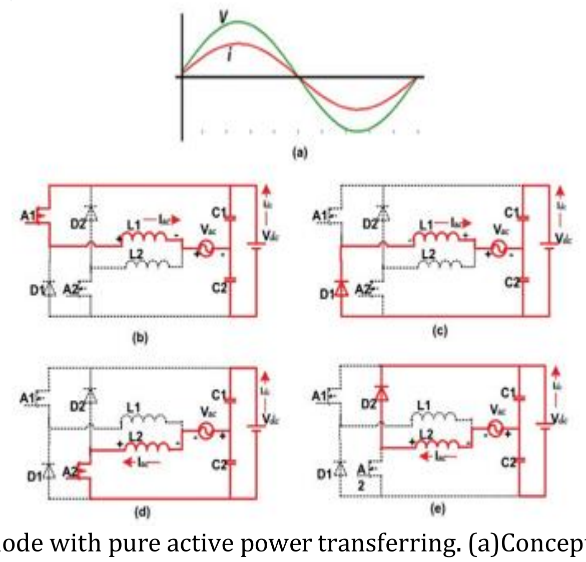

Fig. 4. Operating under inverter mode with pure active power transferring. (a)Conceptual Voltage and Current waveforms. (b)A1is ON.(c)D1isON.(d)A2isON.(e) D2isON.

III. PV PANEL WITHMPPT:

In this paper, the flexibility generation of the PV Panel is tracked by P&O MPPT technique victimization DC-DC Boost device. Every area unit fed to the MPPT rule, That in turn will generate duty magnitude relation in step with power and voltage variations. Firstly, the merchandise of voltage and current is completed to reason power generated. The flexibility distinction, i.e., distinction between the previous and gift values is computed Pold - Pnew. Similarly, the voltage distinction is in addition computed by Vold - Vnew. If modification in power is positive and alter in voltage is negative, it indicates that the operation is at intervals the left side of most wall plug shown in Fig. 5 MPPT rule changes duty magnitude relation of boost device to increase the operative voltage of PV panel. By increasing the operative voltage, power delivery can increase as shown in below.

Within the same means, if operative purpose is within the correct aspect to most wall plug, MPPT rule changes duty relation of boost converter to chop back the operating voltage of PV panel. The algorithmic steps. The P&O rule is to boot referred to as "hill-climbing", but every names talk of with constant rule depending on but it'simplemented. Hill-climbing involves a perturbation on the duty cycle of the power converter and P&O a perturbation among the operating voltage of the DC link between the PV array and conjointly the facility converter. Among the case of the Hill-climbing, worrisome the duty cycle of the power converter implies modifying the voltage of the DC link between the PV array and conjointly the facility converter, so every names talk of with constant technique. Throughout this system, the sign of the last perturbation and conjointly the sign of the last increment among the facility unit of measurement used.

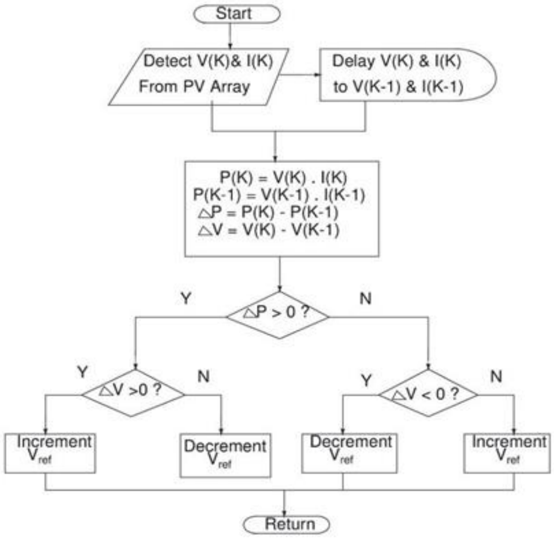

Fig 5. P&O Mppt algorithm

IV. PROPOSED HYSTERESIS CONTROLLER FOR BIDIRECTIONAL POWERFLOW

In order to modify the controller and at a similar time stabilize the system throughout the mode transitions, a physical phenomenon controller is employed. Once current is positive within the rectifier mode, the entire potential unit seconds applied to the inductance L1 over one shift amount square measure as follows:

$(VDC/2 + VAC)D\,rA1 + (VDC/2 + VAC)\,(1 - DrA1) = 0$ (1)

The duty cycle for switch A1 is derived as

$D\,rA1 = 0.5\,(1 - (VAC/(VDC/2)))$ (2)

$= 0.5\,(1 - M\sin(\omega t))$ (3)

Similarly, the duty cycle for switchA2 within the rectifier modecan be derived as follows:

$DrA2 = 0.5(1 + (VAC/(VDC/2)))$ (4)

$= 0.5(1 + M\sin(\omega t))$ (5)

The duty cycle for switch A1 within the electrical converter mode is obtained as

$DiA1 = 0.5(1 + (VAC/(VDC/2)))$ (6)

$= 0.5(1 + M\sin(\omega t))$

$= 0.5(1 + M\sin(\omega t))$ (7)

The duty cycle for switch A2 within the electrical converter mode is obtained as

$DiA2 = 0.5(1-(V_{AC}/(V_{DC}/2)))$ (8)

$= 0.5(1 - M\sin(\omega t))$ (9)

It can be concluded that DrA1 = DiA2 and DrA2 = DiA1.

By ever-changing the current reference from +ito -i , the management

A1 to conduct positive current are going to be used for DA2 to conduct negative current and also the management output applied to DA2 to conduct negative current are going to be used for DA1 to conduct positive current. One controller are often accustomed regulate current below each rectifier and electrical converter modes.

Fig. five shows the whole circuit diagram that features a physical phenomenon current management loop. Current command iref is obtained from the active power command Pref and also the reactive power command Qref. The reference active and reactive power command are often accustomed calculate Im and θ as shown below

$I_m = ((P_{ref}+Q_{ref})/(V_{pk}/2))$ (10)

$\theta = \tan^{-1}(Q_{ref}/P_{ref})$ (11)

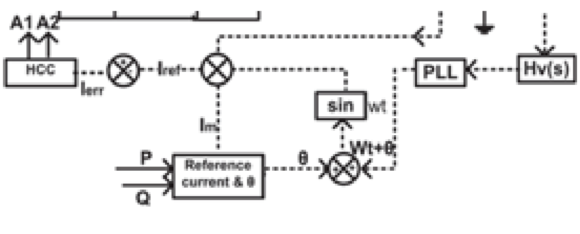

Fig 6. Proposed hysteresis controller

From Fig.6.4Hv(s) is that the voltage detector gain, that is ready to compensate feedback voltage vacation from grid. PLL provides the voltage angle (ωt) of grid. Adding θ to ωt generates reference current wave sort. It compares with injected current iac, supported that the error pulses area unit generated by natural phenomenon current controller A1& A2. By giving exclusively +Pref input to controller, it's going to generate iref partly with grid voltage vacation. The AC-DC device will work as converter, if we've a bent to supply negative active power -Pref and iref is with 1800 half distinction with vacation making the AC-DC device work as rectifier. terribly} very case where, active power Pref is zero and reactive power Qref has some worth as input to controller, it's going to generate iref with 90o half shift.with 1800 half distinction with grid voltage, and at ever instant iref is compared with iref and thus the error is fed to the natural phenomenon current controller relay (HCC). If the error is negative, switch A1 is turned ON in negative zero.5 cycle of voltage. If error is positive, A1 is turned OFF. In positive zero.5 cycle of voltage, A2 and D2 will operate. among the case of converter mode of operation, the controller generates iref having half shift with grid voltage, and at ever instant iref is compared with iref and thus the generated error is feed to the natural phenomenon current controller relay (HCC). If the error is negative, switch A2 is turned OFF in negative zero.5 cycle of voltage; if error is positive, A2 is turned ON. In positive zero.5 cycle of voltage A1 and D1 will operate.

SIMULATION DIAGRAM:

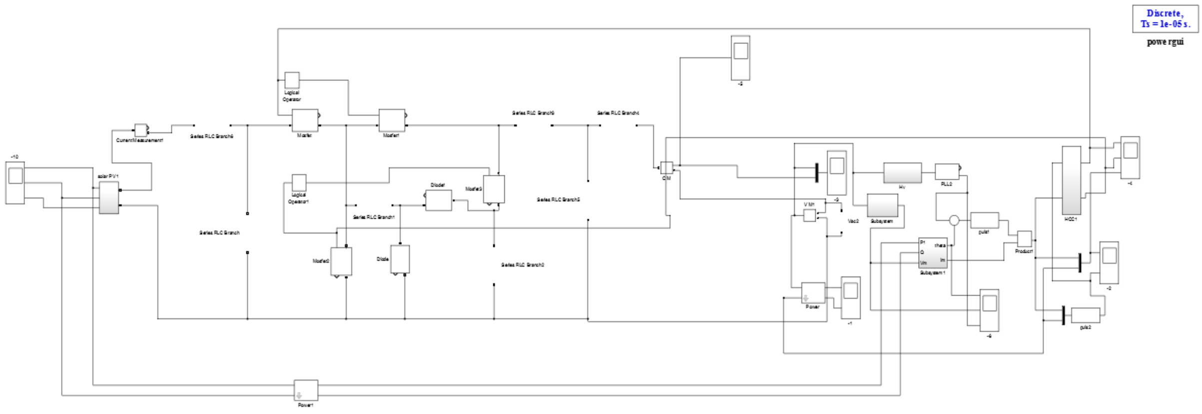

Fig 7. Simulation Diagram of the Proposed system.

EXPLANATION: In the existing system, Solar (PV) for linked to the grid application. In this concept to control the current harmonics by utilizing hysteresis controller. the solar (PV) power systems have actually become popular amongst the renewable energy sources, due to the fact that they produce electrical energy without moving parts, run quietly with no emissions, as well as need little upkeep. A changed p&o based maximum power point monitoring (mppt) controller is made use of which allows the maximum power extraction under diverse irradiation and also temperature level conditions. the present controller for grid connected setting satisfies 2 needs-- specifically,(i) throughout light load condition the excess energy generated from the pv inverter is fed to the grid and (ii) throughout an overload problem or in case of unfavorable weather the tons need is met by both PV inverter and also the grid

SUBSYSTEM:

CONTROLLER:

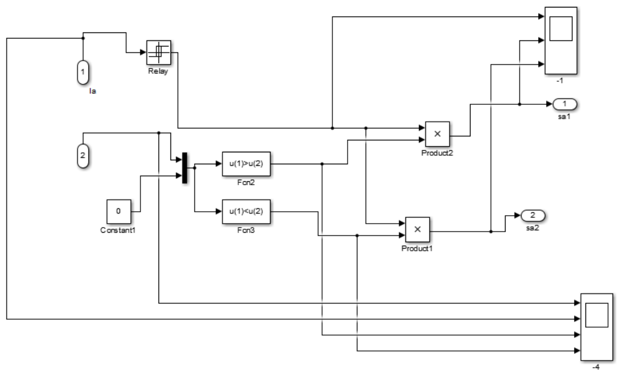

Fig8. Controller of the proposed system

The Hysteresis current controller gives generation of the switching signals for the inverter. Hysteresis-band PWM is primarily an immediate comments present The control circuit creates the sine referral existing wave of required size as well as regularity, and it is compared with the actual stage existing wave. The inverter comes to be an important present source with peak to peak current ripple, which is regulated within the hysteresis band regardless of Vd change. The peak-to top existing ripple and the changing frequency relate to the size of the hysteresis band.

WAVEFORMS

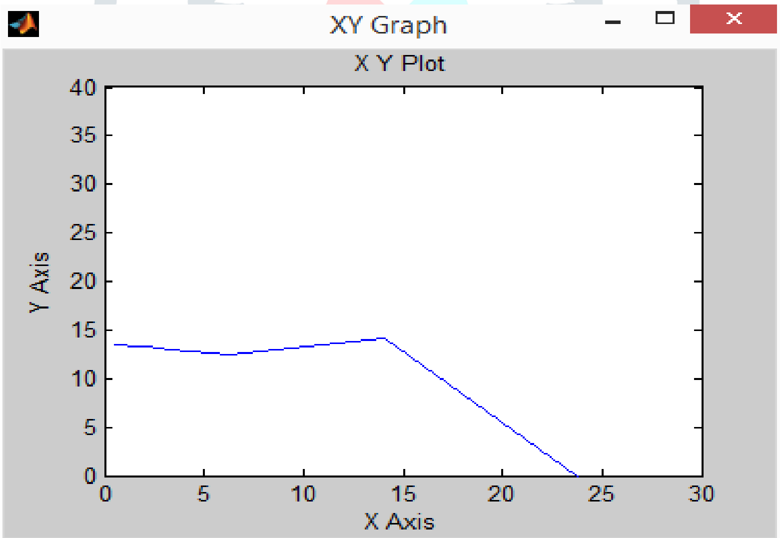

Fig 9. INPUT WAVEFORM

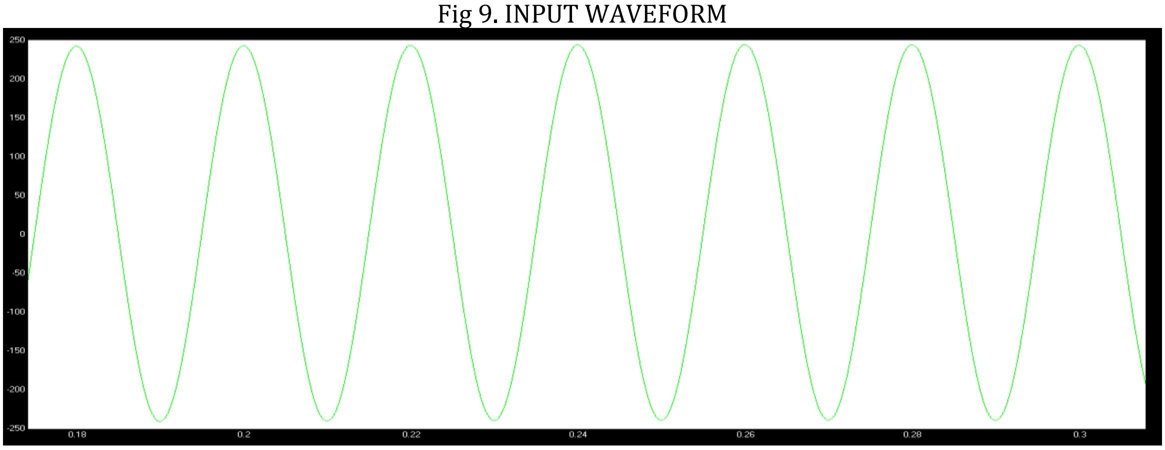

Fig10. OUTPUT WAVEFORM(CURRENT)

Table I

THD % of the both Cases

BASE PAPER	EXTENSION

2.25%	0.08%

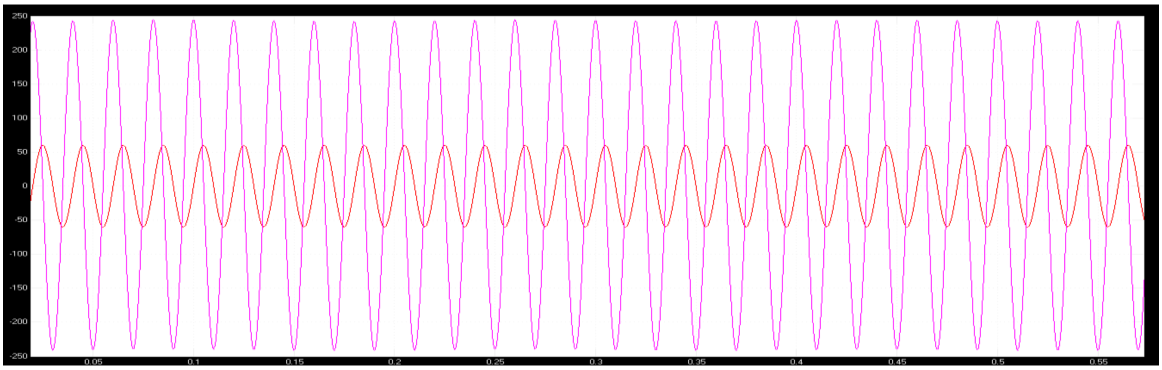

Fig 11. OUTPUT WAVEFORM (VOLTAGES)

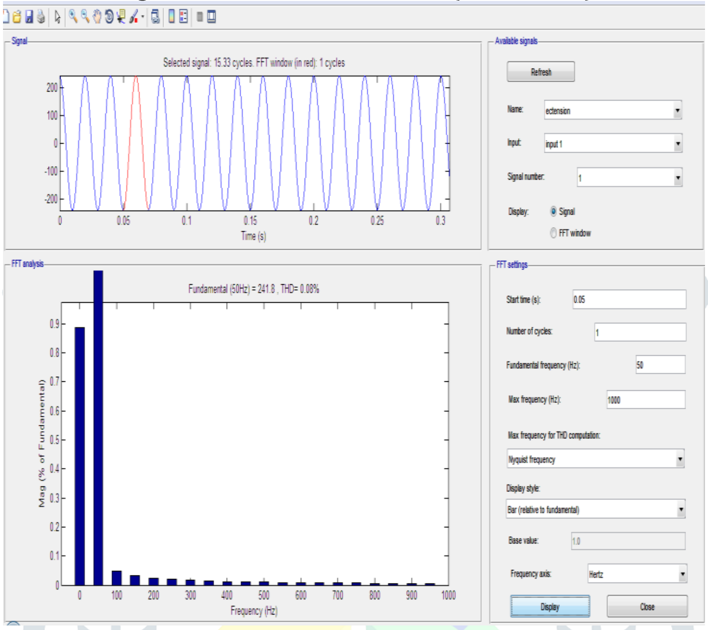

Fig12. THD WAVEFORM.

CONCLUSION

This paper planned a replacement single-phase device less convertor for a grid-tied PV system using a charge pump circuit plan. The concept is planned to induce the negative output voltage among the planned convertor. This new topology generates a three level output voltage by HCC controller. The negative terminal of the planned topology is that an equivalent as a result of the neutral line among the grid; thus, the outpouring current is well sup- smooth and additionally the device is eliminated. The planned topology has in addition the facility to deliver reactive power into the grid. In addition, the planned topology is also accomplished with a mini- mum vary of components; therefore, ensuing power density is also achieved with lower vogue worth. Compared to totally different existing device less topologies, the performance delineated by the pro- expose convertor is nice.

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AUTHOR DETAILS:

Miss MADASU LAYA received a diploma in Electrical and Electronics Engineering from Govt. Polytechnic Medchal College, Medchal , Medchal (D), Telangana, India, and received a B.Tech degree in Holy Mary Institute of Technology and Science ,Bogaram (V), Keesara (M), Medchal (D), Hyderabad , Telangana, India from JNTUH University in 2021.And Pursuing M.Tech in Electrical Power Systems at Holy Mary Institute of Technology and Science , Bogaram (V), Keesara (M), Medchal (D), Hyderabad ,Telangana ,India ,in the department of electrical and electronics engineering .

MRS. A.ANURADHA received the B.TECH degree in EEE from Christu Jyothi institute of technology, Yeshwanthapur (V), Jangaon (D), Telangana, INDIA, from JNTU University and MTECH in Electrical Power System in Vignana Bharati Institute of Technology and sciences, near Ghatkesar Bogaram (V), Medchal (D), Hyderabad, Telangana, INDIA. She has 2 years of teaching experience, currently working as an Assistant professor in Holy Mary Institute of Technology and sciences, Bogaram (V), Medchal (D), Hyderabad, Telangana, INDIA in EEE department. Her interested areas are Electrical power systems0"